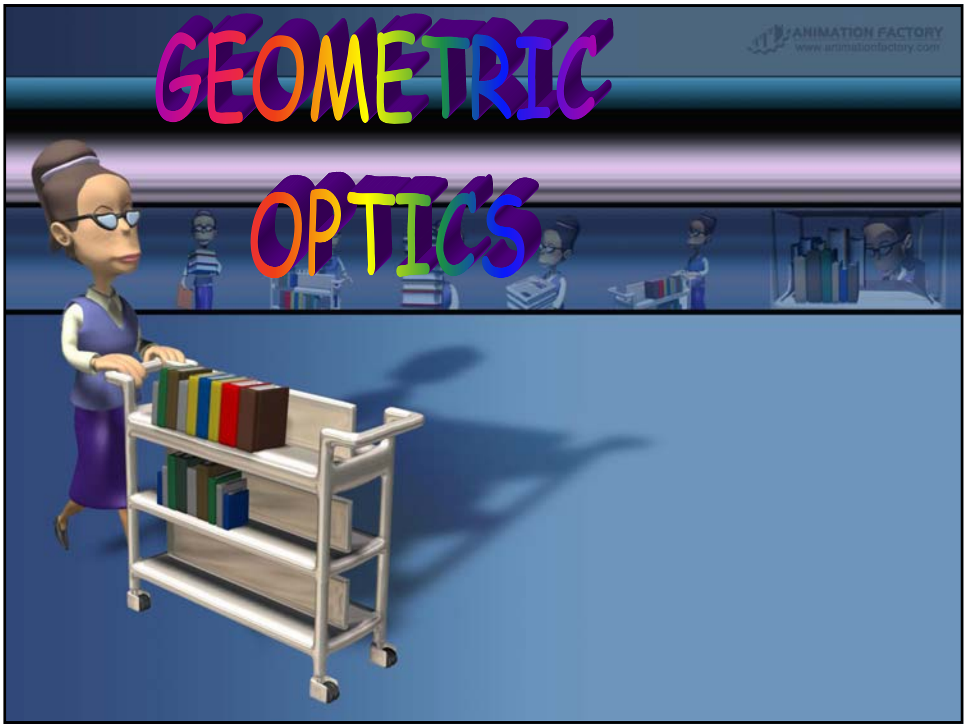
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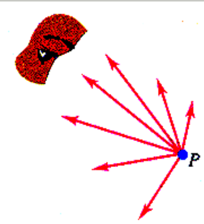
Chapter Objectives
• Analysis of image-forming optical devices (plane mirror).
• Study how images are formed by curved mirrors, by refracting surfaces, and by thin lenses.
• Understanding many familiar optical instruments.

Chapter Outline

1. Reflection and Refraction at a Plane Surface
2. Reflection at a Spherical Surface
3. Refraction at a Spherical Surface
4. Thin Lenses
5. Camera
6. The Eye
7. The Magnifier
8. Microscopes and Telescopes

Object - anything from which light rays radiate.

Point object – no physical extent
Extended object – real objects with length, width, and height.

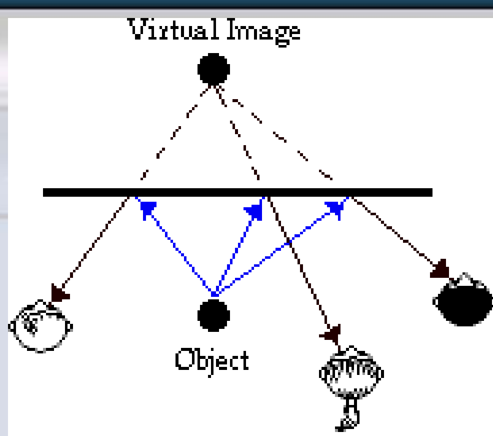


35–1 Light rays radiate from a point object in all directions.

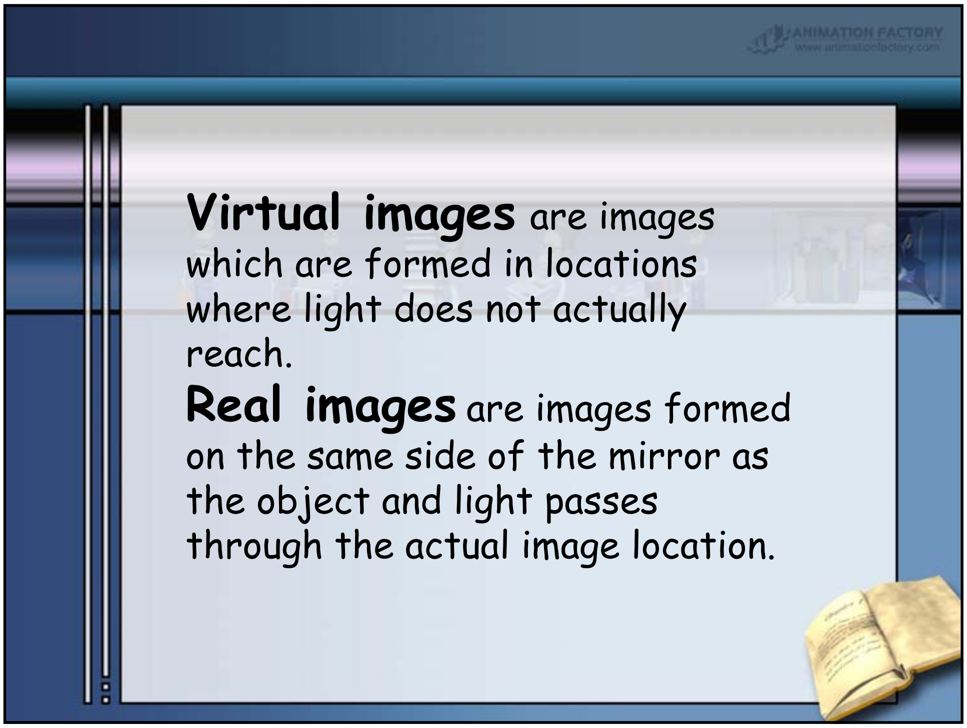
Luminous objects are objects which generate their own light.

Illuminated objects are objects, which are capable of reflecting light to our eyes.

Image is a position in space where all the reflected light appears to diverge from. Since light from the object appears to diverge from this location, a person who sights along a line at this location will perceive a replica or reproduction of the actual object.



All observers would perceive light to be diverging from the same point - the image point.


Virtual images are images which are formed in locations where light does not actually reach.
Real images are images formed on the same side of the mirror as the object and light passes through the actual image location.

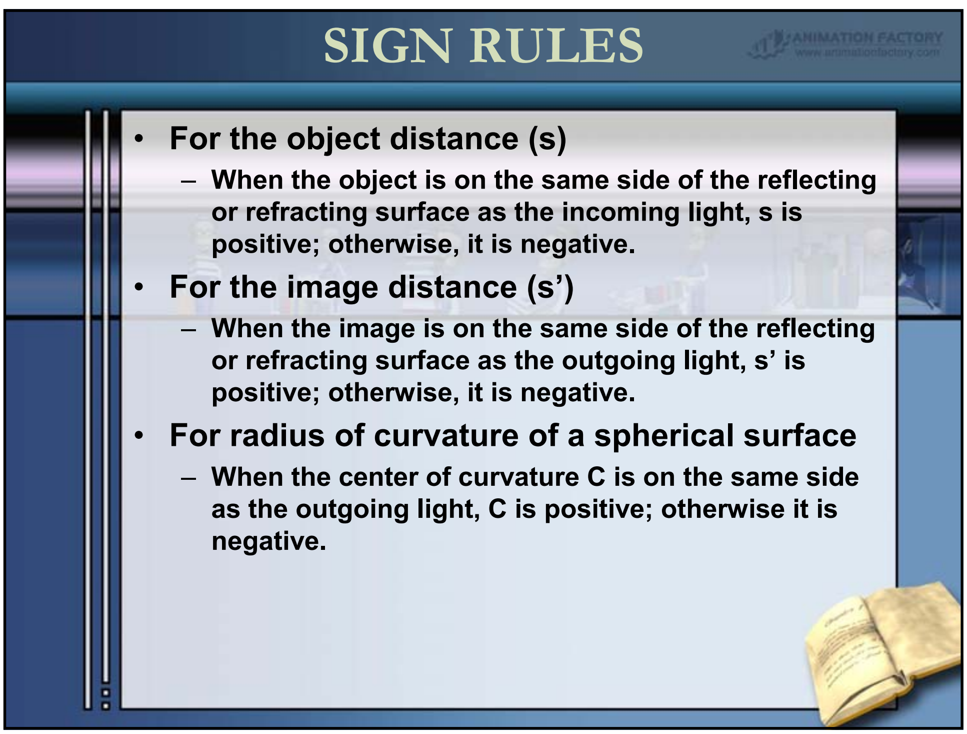

SIGN RULES
• For the object distance (s)
– When the object is on the same side of the reflecting or refracting surface as the incoming light, s is positive; otherwise, it is negative.
• For the image distance (s')
– When the image is on the same side of the reflecting or refracting surface as the outgoing light, s' is positive; otherwise, it is negative.
• For radius of curvature of a spherical surface
– When the center of curvature C is on the same side as the outgoing light, C is positive; otherwise it is negative.

IMAGE FORMATION BY REFLECTING SURFACES

IMAGE FORMATION FOR PLANE MIRROR

$$s = -s'$$

(lateral magnification)

$$m_T = y'/y = 1$$

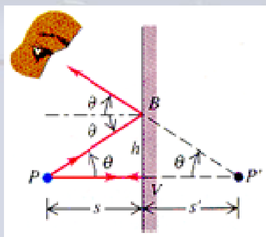
Image formed is virtual.

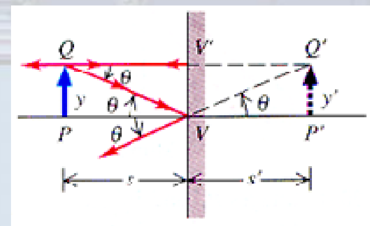
where
s,s' = object, image distance, respectively;
y,y' = object, image height, respectively

IMAGE FORMATION FOR PLANE MIRROR

$s = -s'$

$m_T = y'/y = 1$ (lateral magnification)





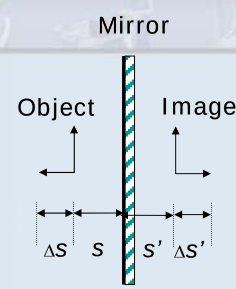
where
s,s' = object, image distance, respectively;
y,y' = object, image height, respectively

IMAGE FORMATION FOR PLANE MIRROR

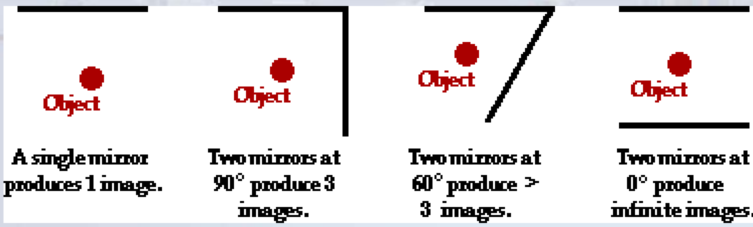
Longitudinal magnification is defined as the ratio of the image length to the object length along the direction of the normal to the mirror:

$$m_L = \frac{\Delta s'}{\Delta s} = -1$$

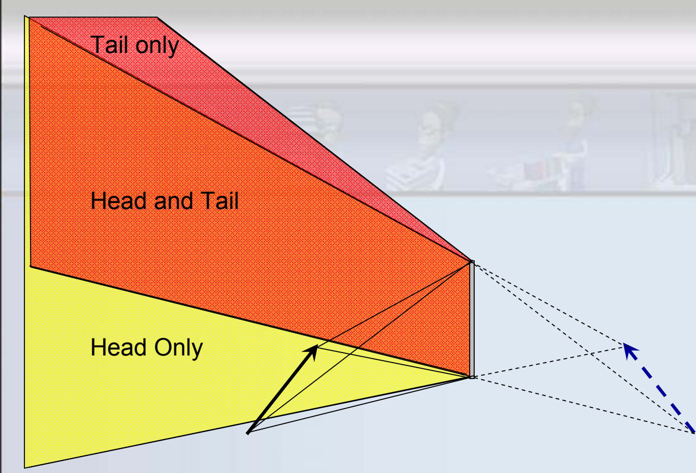
It is also obvious that m_L has a magnitude of 1. The minus sign is introduced to indicate the front-back reversal of the image.



Other Multiple Mirror Systems



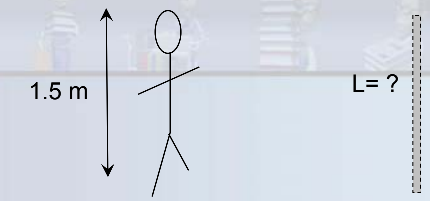
Can the image be seen from all viewing locations?



- No, the size of the mirror will limit the viewing area
- Determine viewing zone by look at rays that intersect the mirrors edge

Now try this…

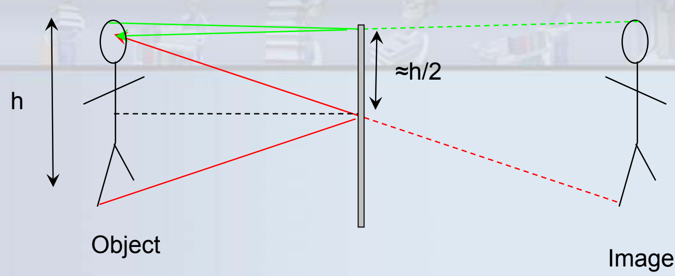
- **How big does a mirror need to be for a 1.5-m friend to be able to see her full image?**



1. 0.75 m
2. 1.50 m
3. 3.00 m
4. It depends where she stands

Solution…

- **How big does a mirror need to be for a 1.5-m friend to be able to see her full image?**



Approximately 0.75 m, it does not matter where she stands!

IMAGE FORMATION FOR CURVED MIRRORS

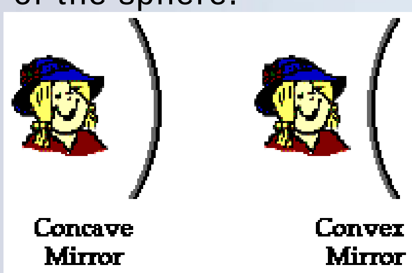
Spherical mirrors

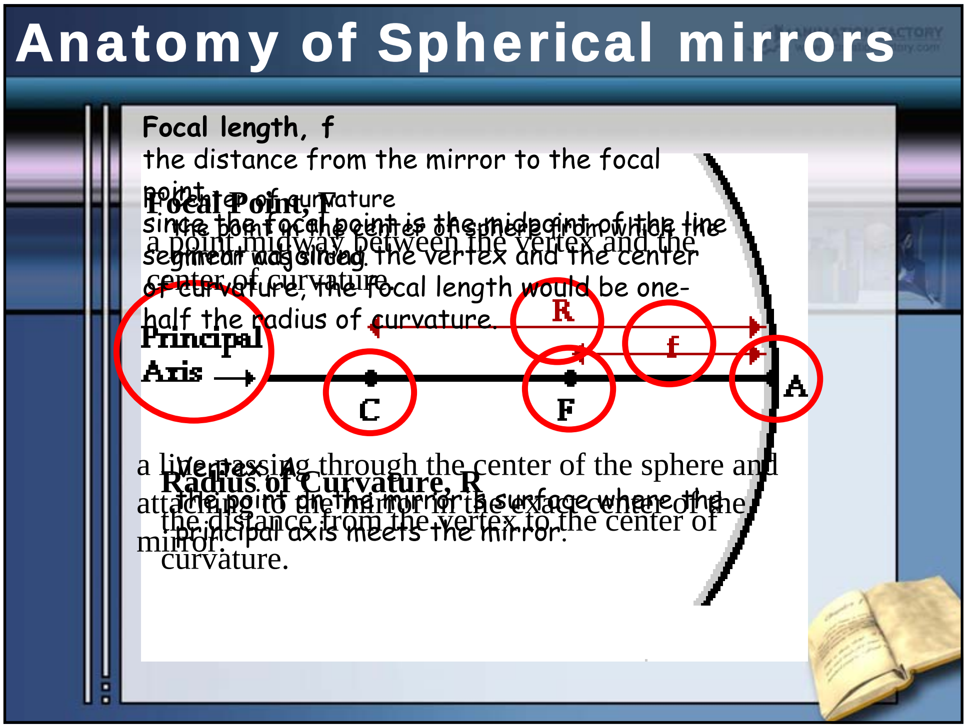
- **curved mirrors which have the shape of spheres.**

Two types of spherical mirrors

Concave mirrors were silvered on the inside of the sphere

Convex mirrors were silvered on the outside of the sphere.

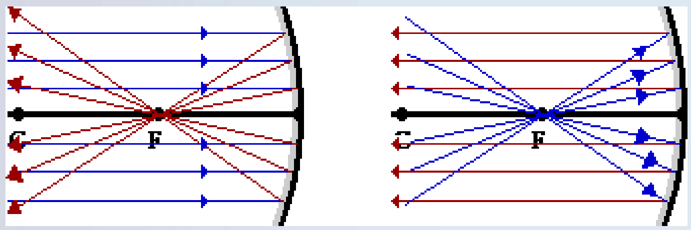



Anatomy of Spherical mirrors
Focal length, f
the distance from the mirror to the focal point
since the focal point is the midpoint of the line segment adjoining the vertex and the center of curvature, the focal length would be one-half the radius of curvature.
Center of curvature
the point in the center of sphere from which the mirror was sliced.
Focal Point, F
a point midway between the vertex and the center of curvature.
Principal Axis
a line passing through the center of the sphere and attaching to the mirror in the exact center of the mirror.
Vertex, A
the point on the mirror's surface where the principal axis meets the mirror.
Radius of Curvature, R
the distance from the vertex to the center of curvature.
R
f
C
F
A


CAVE
nd
VEX
ROR

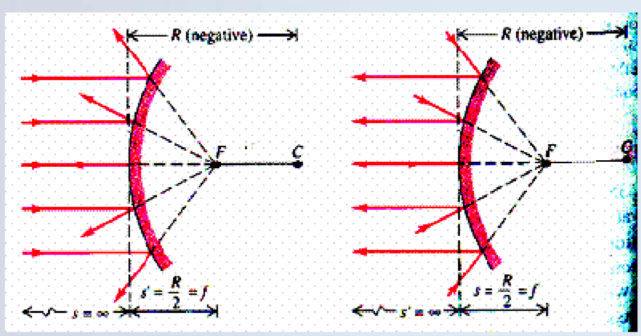
•Any incident ray traveling parallel to the principal axis on the way to the mirror will pass through the focal point upon reflection.

•Any incident ray passing through the focal point on the way to the mirror will travel parallel to the principal axis upon reflection.



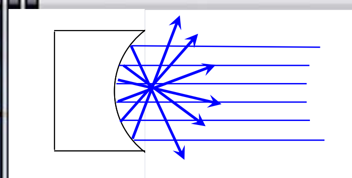
•Any incident ray traveling parallel to the principal axis on the way to a convex mirror will reflect in a manner that its extension will pass through the focal point.

•Any incident ray traveling towards a convex mirror such that its extension passes through the focal point will reflect and travel parallel to the principal axis.



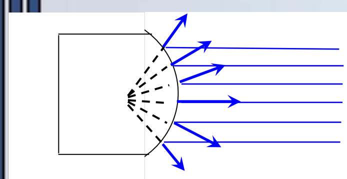
Convex and Concave Mirrors

Concave Mirror



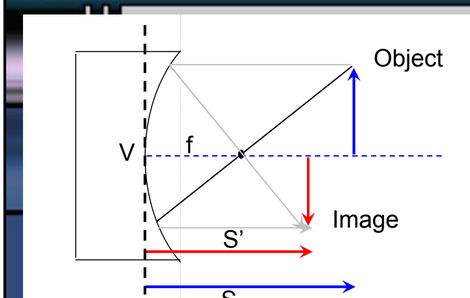
- Light is focused to a point R/2 on the object side of vertex
- Focal length is + R/2
- This mirror can produce real images!

Convex Mirror



- Light appears to be diverging from a point R/2 on the image side of the vertex
- Focal length is - R/2
- This mirror can only produce virtual images!

Image formation by spherical mirrors



$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'} \qquad m_T = -\frac{s'}{s}$$

- **Object distance = S**
- **Image distance = S'**
- **Focal Length = f**
- **All distances are measured from the vertex, V**
- **All distances positive if in front of the mirror, negative if behind the mirror!**
- **The mirror equation can be used to calculate any one of these distances if the other two are known**
- **The magnification is the length of the image divided by the length of the object. It is determined by similar triangles**

Lateral & longitudinal magnifications of concave mirror

The lateral magnification m_T of a concave mirror

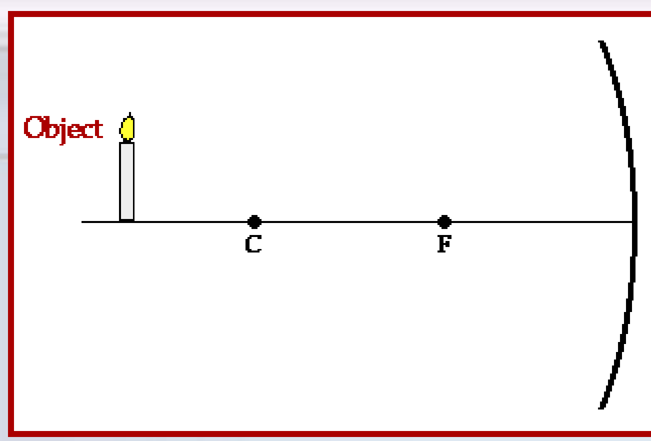
$$m_T = \frac{y'}{y} = -\frac{s'}{s}$$

The minus sign is introduced to indicate that the image is inverted.

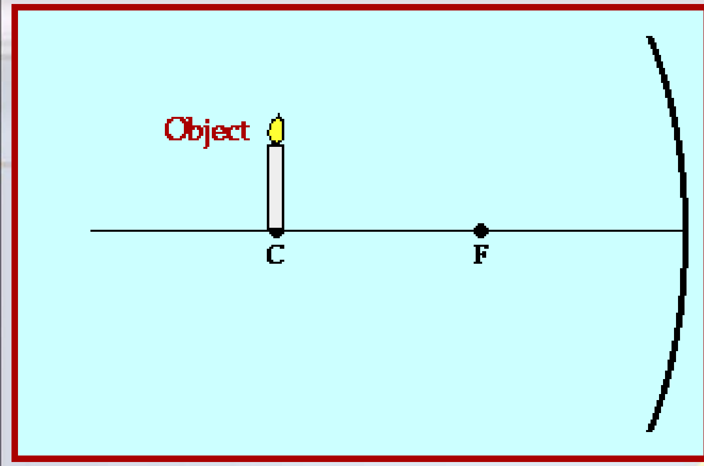
The longitudinal magnification m_L is defined as before (i.e. $m_L = \Delta s'/\Delta s = ds'/ds$). Using the mirror equation, we have

$$-\frac{ds}{s^2} - \frac{ds'}{s'^2} = 0 \quad \Rightarrow \quad m_L = \frac{ds'}{ds} = -\frac{s'^2}{s^2} = -m_T^2$$

Object Located Beyond the Center of Curvature



Object Located At the Center of Curvature



Object Located Between the Center of Curvature and the Focal Point

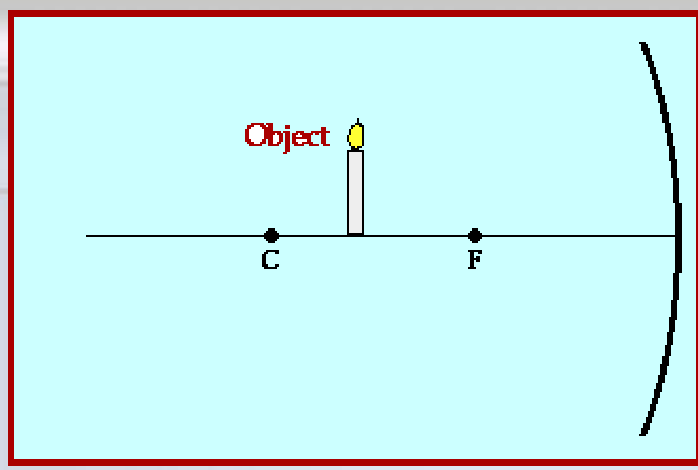
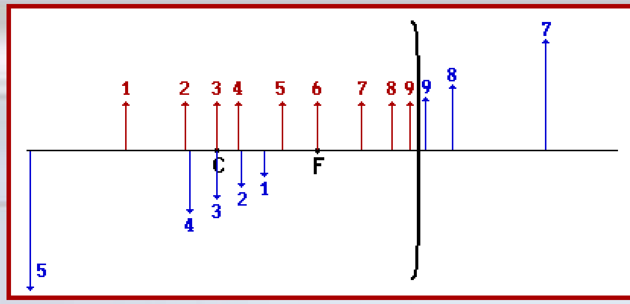
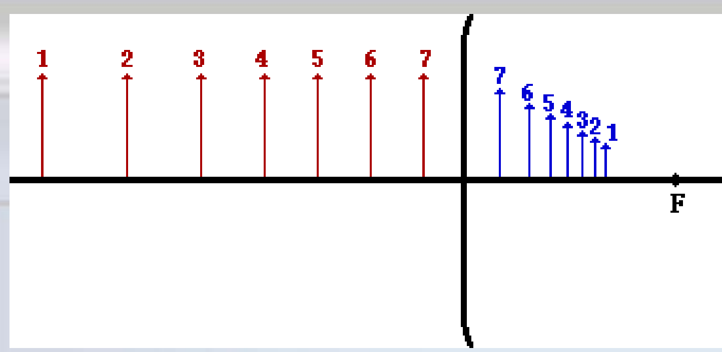


Image Characteristics for Concave Mirrors



MIRROR TYPE	OBJECT LOCATION	IMAGE			SIGN			
		Location	Type	Orientation	f	R	s	s'
Concave	$\infty > s > 2f$	$f < s' < 2f$	Real minified	Inverted	+	+	+	+
	$s = 2f$	$s' = 2f$	Real $m = 1$	Inverted	+	+	+	+
	$f < s < 2f$	$\infty > s' > 2f$	Real magnified	Inverted	+	+	+	+
	$s = f$	$\pm\infty$			+	+	+	+
	$s < f$	$\|s'\| > s$	Virtual magnified	Upright	+	+	+	-

Image Characteristics for Convex Mirrors



MIRROR TYPE	OBJECT LOCATION	IMAGE			SIGN			
		Location	Type	Orientation	f	R	s	s'
Convex	Anywhere	$\|s'\| < f$ $s > \|s'\|$	Virtual minified	Upright	-	-	+	-

TABLE FOR MIRRORS

MIRROR TYPE	OBJECT LOCATION	IMAGE			SIGN			
		Location	Type	Orientation	f	R	s	s'
Plane	Anywhere	Behind the mirror	Virtual $m=1$	Upright			+	-
Concave	$\infty > s > 2f$	$f < s' < 2f$	Real minified	Inverted	+	+	+	+
	$s = 2f$	$s' = 2f$	Real $m = 1$	Inverted	+	+	+	+
	$f < s < 2f$	$\infty > s' > 2f$	Real magnified	Inverted	+	+	+	+
	$s = f$	$\pm\infty$			+	+	+	+
	$s < f$	$\lvert s' \rvert > s$	Virtual magnified	Upright	+	+	+	-
Convex	Anywhere	$\lvert s' \rvert < f$ $s > \lvert s' \rvert$	Virtual minified	Upright	-	-	+	-

34.8. An object is 24.0 cm from the center of a silvered spherical glass Christmas tree ornament 6.00 cm in diameter. What are the position and magnification of its image?

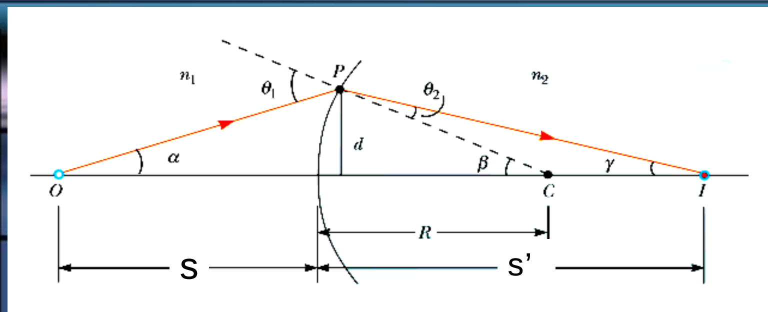
34.9. A coin is placed next to the convex side of a thin spherical glass shell having a radius of curvature of 18.0 cm. An image of the 1.5-cm-tall coin is formed 6.00 cm behind the glass shell. Where is the coin located? Determine the size, orientation, and nature (real or virtual) of the image.

34.10. You hold a spherical salad bowl 90 cm in front of your face with the bottom of the bowl facing you. The salad bowl is made of polished metal with a 35-cm radius of curvature. (a) Where is the image of your 2.0-cm-tall nose located? (b) What are the image's size, orientation, and nature (real or virtual)?

34.65. A concave mirror is to form an image of the filament of a headlight lamp on a screen 8.00 m from the mirror. The filament is 6.00 mm tall, and the image is to be 36.0 cm tall. (a) How far in front of the vertex of the mirror should the filament be placed? (b) What should be the radius of curvature of the mirror?

34.68. Rear-View Mirror. A mirror on the passenger side of your car is convex and has a radius of curvature with magnitude 18.0 cm. (a) Another car is seen in this side mirror and is 13.0 m behind the mirror. If this car is 1.5 m tall, what is the height of the image? (b) The mirror has a warning attached that objects viewed in it are closer than they appear. Why is this so?

REFRACTION AT A SPHERICAL SURFACE



(Snell's law)

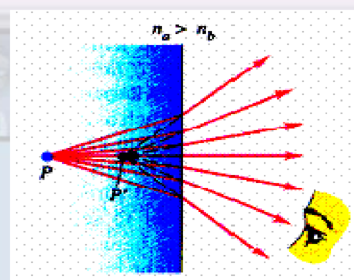
$$n_1 \sin\theta_1 = n_2 \sin\theta_2$$

$$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R}$$

Notice that for $R = \infty$, which corresponds to a flat surface, we have

$$\frac{n_1}{s} + \frac{n_2}{s'} = 0$$

$$s' = -\frac{n_2}{n_1} s$$

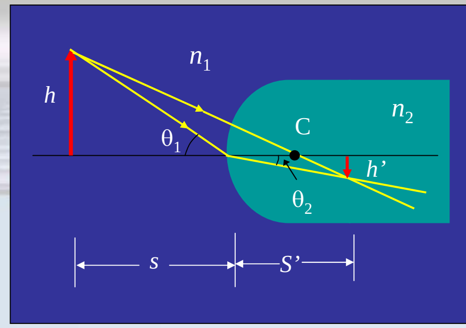


35–3 The rays entering the eye after refraction at the plane interface look as though they had come from point *P'*, the image point for object *P*. When $n_a > n_b$, as shown here, the image point *P'* is closer to the surface than the object point *P*. The angles of incidence have been exaggerated for clarity.

Lateral and longitudinal magnifications

$$\sin\theta_1 \approx \tan\theta_1 = \frac{h}{s}$$

$$\sin\theta_2 \approx \tan\theta_2 = -\frac{h'}{s'}$$



Hence

$$\frac{n_1 h}{s} = -\frac{n_2 h'}{s'}$$

Therefore the lateral magnification is $m_T = \frac{h'}{h} = -\frac{n_1 s'}{n_2 s}$

The longitudinal magnification is $m_L = -\frac{n_1}{n_2} m_T^{\ 2}$

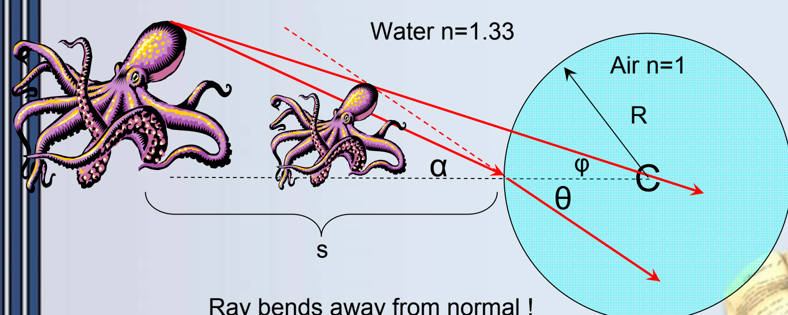
34.16. A tank whose bottom is a mirror is filled with water to a depth of 20.0 cm. A small fish floats motionless 7.0 cm under the surface of the water. (a) What is the apparent depth of the fish when viewed at normal incidence? (b) What is the apparent depth of the image of the fish when viewed at normal incidence?

34.17. A Spherical Fish Bowl. A small tropical fish is at the center of a water-filled, spherical fish bowl 28.0 cm in diameter. (a) Find the apparent position and magnification of the fish to an observer outside the bowl. The effect of the thin walls of the bowl may be ignored. (b) A friend advised the owner of the bowl to keep it out of direct sunlight to avoid blinding the fish, which might swim into the focal point of the parallel rays from the sun. Is the focal point actually within the bowl?

34.18. The left end of a long glass rod 6.00 cm in diameter has a convex hemispherical surface 3.00 cm in radius. The refractive index of the glass is 1.60. Determine the position of the image if an object is placed in air on the axis of the rod at the following distances to the left of the vertex of the curved end: (a) infinitely far, (b) 12.0 cm; (c) 2.00 cm.

34.20. The left end of a long glass rod 8.00 cm in diameter, with an index of refraction 1.60, is ground and polished to a convex hemispherical surface with a radius of 4.00 cm. An object in the form of an arrow 1.50 mm tall, at right angles to the axis of the rod, is located on the axis 24.0 cm to the left of the vertex of the convex surface. Find the position and height of the image of the arrow formed by paraxial rays incident on the convex surface. Is the image erect or inverted?

- **An octopus is a distance s away from the helmet of a deep sea diver. Where is the image of the octopus? For this problem, ignore the thin glass window and treat the helmet as an air bubble of radius R.**
- **To locate the image, choose two rays and find intersection**
  - **1 passing through center is not refracted**
  - **1 passing through vertex – use Snell's law**



Ray bends away from normal !

- Typically, the angles will be fairly small (< 15 °)
- sin α ~ α, cos α ~ 1, so tan ~ α, etc.
- After a "little" geometry we find:

$$n_1 \sin\alpha = n_2 \sin\theta \quad \Rightarrow \quad n_1\alpha = n_2\theta$$

$$\frac{n_1}{s} + \frac{n_2}{s'} = \frac{n_2 - n_1}{R} \quad \text{with} \quad M = -\frac{n_1 s'}{n_2 s}$$

Single interface

Where:
Object distance, S, is (+) when object is to left of vertex
Image distance, S', is (+) when image is to right of vertex
Radius of surface, R, is (+) if the center (C) is to right of vertex
(Light is incident from the left side)

Example

- So if our helmet had a 5.0 m radius of curvature and the 2m octopus was 10 m from the edge of the helmet,

$$\frac{1.33}{10\,m} + \frac{1.0}{s'} = \frac{1-1.33}{5\,m} \quad \Rightarrow \quad \frac{1.0}{s'} = -.067\,m^{-1} - .133\,m^{-1}$$

Image distance $s' = -\frac{1.0}{0.2} = -5\,m$

- The image of the octopus would appear 5.0 m to the left of the interface,
- The octopus would appear upright and about 1.33 m long.

Magnification

$$M = -\frac{1.33 \cdot (-5.0m)}{1.0 \cdot (10.0m)} = 0.665$$

Example : One end of a cylindrical glass rod (n = 1.5) is ground to a hemispherical surface of R = 20 mm. Find the image distance of a point object on the axis of the rod, 80 mm to the left of the vertex. If the height of the object is 1 mm, calculate the height of its image. The rod is in air.

$R = 20,\ p = 80,\ n_1 = 1,\ n_2 = 1.5$

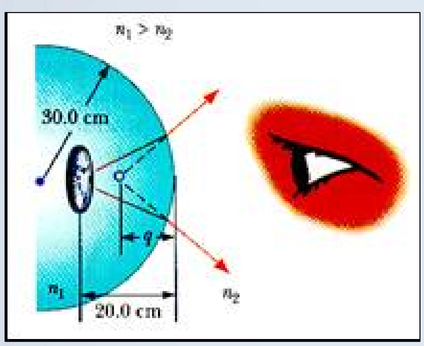
$$\frac{1}{80} + \frac{1.5}{q} = \frac{1.5-1}{20} \quad \Rightarrow \quad q = 120 \text{ mm}$$

$$M = -\frac{n_1 q}{n_2 p} = \frac{1 \times 120}{1.5 \times 80} = -1 \quad \Rightarrow \quad \boxed{h' = 1 \times M = -1 \text{ mm}}$$

The image has the same size as the object but is inverted.

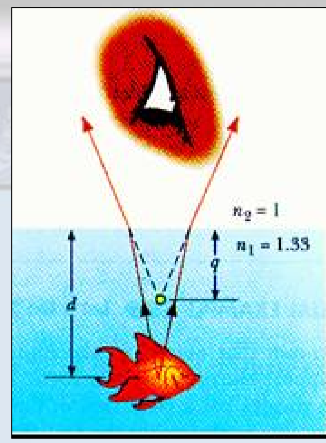
Gaze into the Crystal Ball

A coin 2.00 cm in diameter is embedded in a solid glass ball of radius 30.0 cm. The index of refraction of the ball is n_1 = 1.5, and the coin is 20.0 cm from the surface.Find the position of the image.



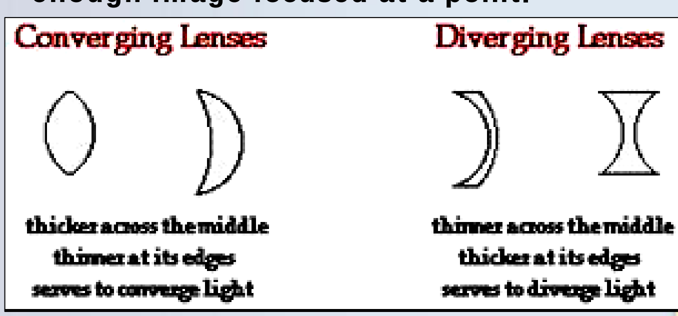
The One That Got Away

A small fish is swimming at a depth **d** below the surface of a pond. What is the apparent depth of the fish as viewed from directly overhead?



LENS

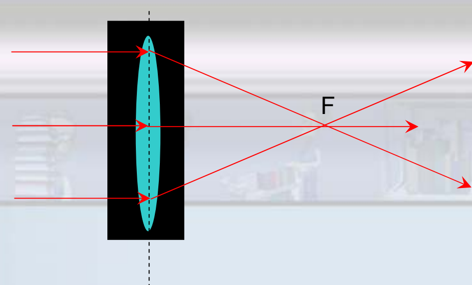
- carefully ground or molded piece of transparent material which refracts light rays in such as way as to form an image.
- Lenses can be thought of as a series of tiny refracting lenses, each of which refracts light to produce their own image. When these prisms act together, they produce a bright enough image focused at a point.



There are two classes of lens

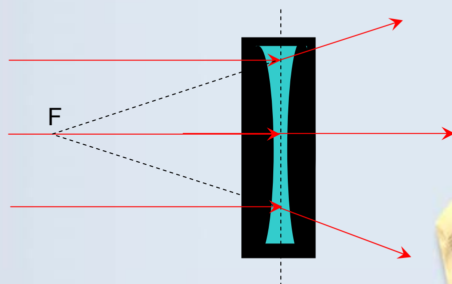
Converging or Positive Lens (f > 0)

- Can produce either real or virtual images
- Plano-convex or biconvex



Diverging or Negative Lens (f < 0)

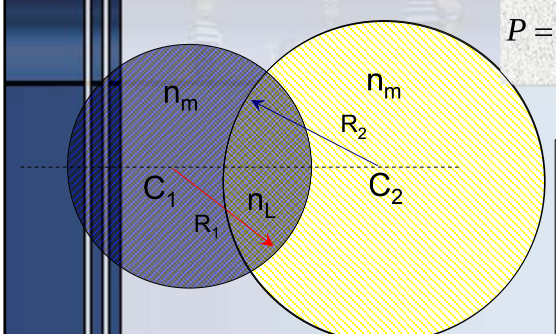
- Can only produce virtual images
- Plano-concave, biconcave, or meniscus



What is the focal length for a thin lens?

- **For spherical ground surfaces, the lens maker's equation is used to determine the focal length:**

$$P = \frac{1}{f} = \frac{(n_g - n_m)}{n_m}\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$



Sign convention:

If Center is:
Left of surface, R<0
Right of surface, R>0

- The focusing power is measured in Diopters (1 D = 1 m $^{-1}$)

Thin lenses: useful for forming images

- Laws of refraction apply at each interface

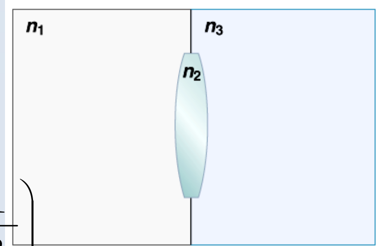
$$\frac{n_1}{s}+\frac{n_3}{s'}=\frac{n_2-n_1}{R_1}+\frac{n_3-n_2}{R_2}$$

Special case: $n_1=n_3$

$$\frac{n_1}{s}+\frac{n_1}{s'}=\frac{n_2-n_1}{n_1}\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

If $n_1=n_3=\text{air}=1$

$$\frac{1}{s}+\frac{1}{s'}=(n_{Lens}-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$



Focal Point and Focal Length

Lens maker's equation:

$$\frac{1}{f}=\frac{n_2-n_1}{n_1}\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

Then:

$$\frac{1}{s}+\frac{1}{s'}=\frac{1}{f}$$

The total refractive power is the sum of the powers from each interface

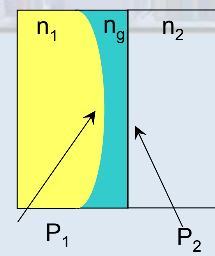
- **Another way of looking at the lensmaker's equation…**

$$P = P_1 + P_2$$

Measured in Diopters (1 D = 1 m^{-1})

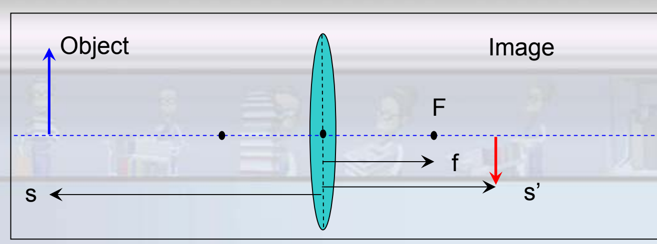
$$P_1 = \frac{1}{f_1} = \frac{(n_g - n_1)}{R_1}$$

$$P_2 = \frac{1}{f_2} = \frac{(n_2 - n_g)}{R_2}$$



A planar surface has no refractive power regardless of the index difference!

Image formation by thin spherical lenses



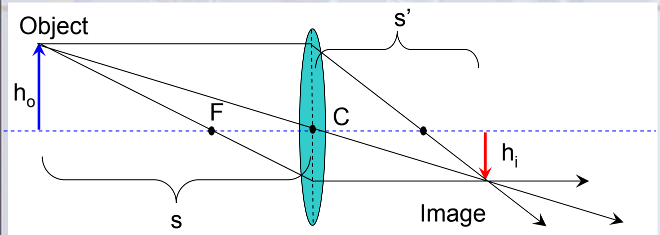
Thin lens equation:

$$\frac{1}{f} = \frac{1}{s} + \frac{1}{s'}$$

- **All distances are from the center of the lens**
- **s > 0 to left of lens**
- **s' > 0 to right of lens**
- **f > 0 to right of lens**

Locating the image produced by a thin lenses

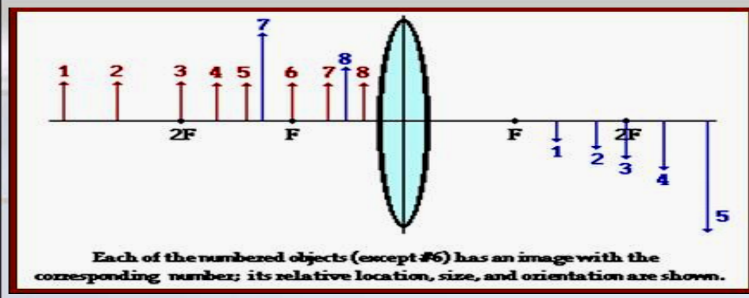
- Any ray parallel to the optical axis will refract through the focal point
- Any ray passing through the focal point will refract parallel to the optical axis
- Any ray drawn through the center of the lens will not deviate
- The image is located where ALL THREE rays intersect



$$M = \frac{h_i}{h_o} = -\frac{s'}{s}$$

CONVEX LENS

Image Characteristics for Convex Lens

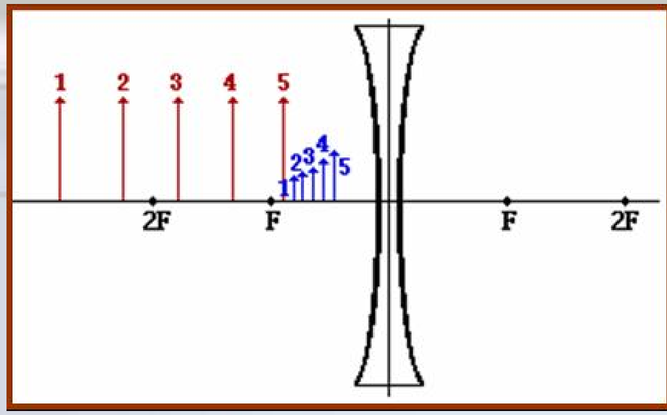


Each of the numbered objects (except #6) has an image with the corresponding number; its relative location, size, and orientation are shown.

LENS TYPE	OBJECT LOCATION	IMAGE			SIGN				
		Location	Type	Orientation	f	R_1	R_2	s	s'
Convex	$\infty > s > 2f$	$f < s' < 2f$	Real minified	Inverted	+	+	-	+	+
	$s = 2f$	$s' = 2f$	Real m =1	Inverted	+	+	-	+	+
	$f < s < 2f$	$\infty > s' > 2f$	Real magnified	Inverted	+	+	-	+	+
	$s = f$	$\pm\infty$			+	+	-	+	+
	$s < f$	$\lvert s' \rvert > s$	Virtual magnified	Upright	+	+	-	+	-

CONCAVE LENS

Image Characteristics for Concave Lens



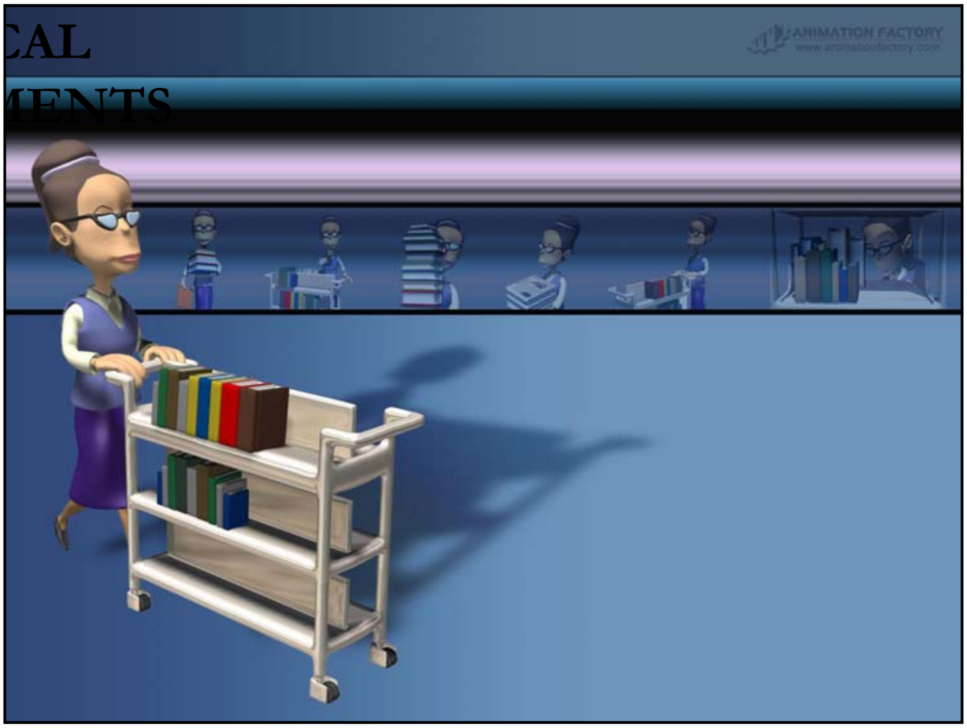
LENS TYPE	OBJECT LOCATION	IMAGE			SIGN				
		Location	Type	Orientation	f	R_1	R_2	s	s'
Concave	Anywhere	$\lvert s' \rvert < \lvert f \rvert$	Virtual minified	Upright	-	-	+	+	-

34.24. A lens forms an image of an object. The object is 16.0 cm from the lens. The image is 12.0 cm from the lens on the same side as the object. (a) What is the focal length of the lens? Is the lens converging or diverging? (b) If the object is 8.50 mm tall, how tall is the image? Is it erect or inverted? (c) Draw a principal-ray diagram.

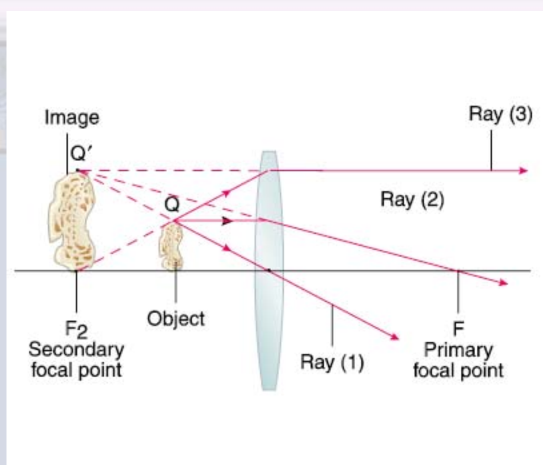
34.25. A converging meniscus lens (see Fig. 34.32a) with a refractive index of 1.52 has spherical surfaces whose radii are 7.00 cm and 4.00 cm. What is the position of the image if an object is placed 24.0 cm to the left of the lens? What is the magnification?

34.26. A converging lens with a focal length of 90.0 cm forms an image of a 3.20-cm-tall real object that is to the left of the lens. The image is 4.50 cm tall and inverted. Where are the object and image located in relation to the lens? Is the image real or virtual?

34.27. A converging lens forms an image of an 8.00-mm-tall real object. The image is 12.0 cm to the left of the lens, 3.40 cm tall, and erect. What is the focal length of the lens? Where is the object located?

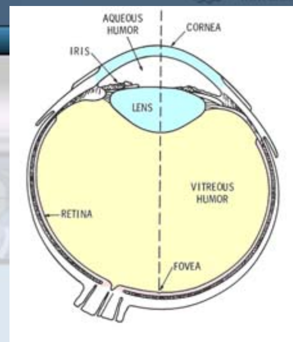


Magnifying Glass



The Eye

- **Eye forms image on retina, where light is sensed**
  - **Cornea does 80% of the work, with the lens providing slight tweaks (accommodation, or adjusting)**

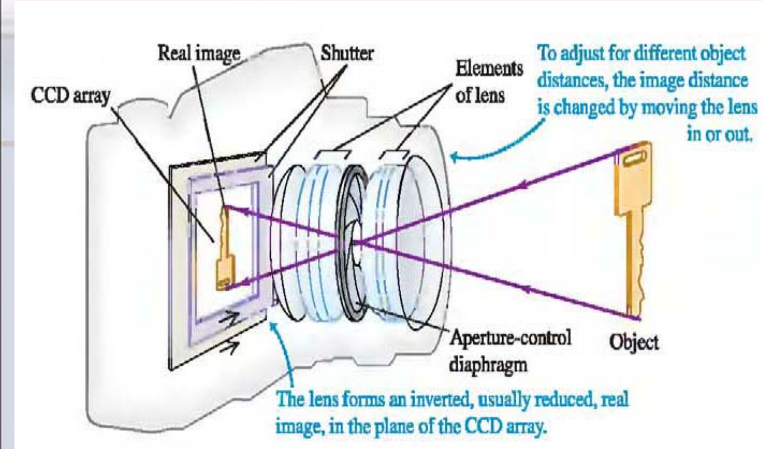


Refractive indices:

air:	**1.0**
cornea:	**1.376**
fluid:	**1.336**
lens:	**1.396**

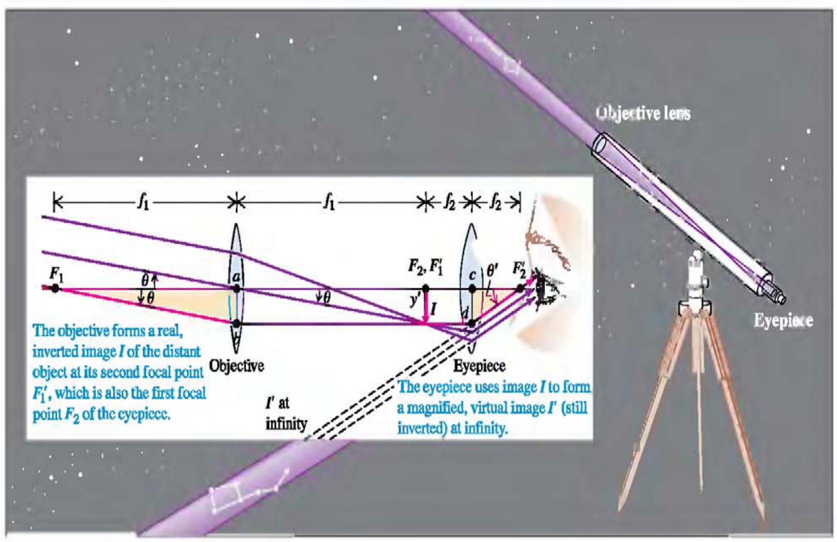
Central field of view (called fovea) densely plastered with receptors for high resolution & acuity. Fovea only a few degrees across.

The Digital Camera

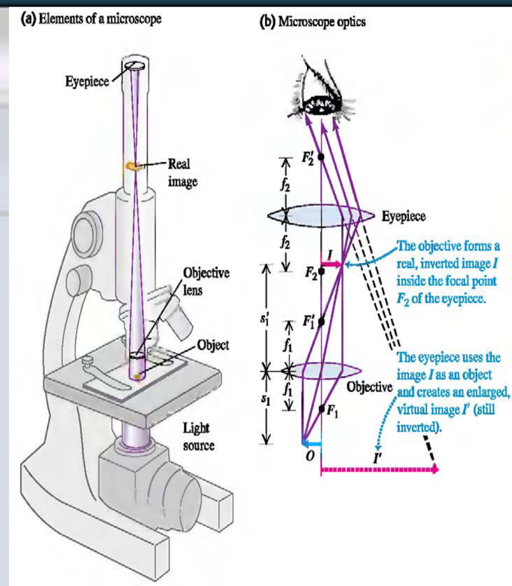


The Telescope

34.53 Optical system of an astronomical refracting telescope.



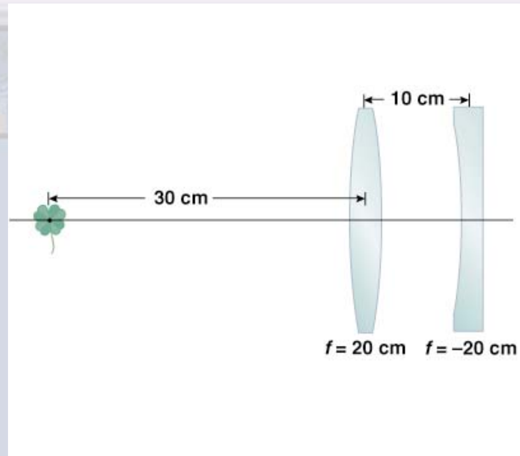
Microscope



LOADING

3%

Example



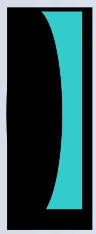
Example

- A lucite plano-concave lens is to have a focal length of -36 cm when the lens is immersed in water. If lucite has an index of refraction of 1.51, determine the radii of curvature of the two sides.

- **A Plano-concave lens is a lens that has one flat surface and one concave surface.**
- **What is the radius of curvature for a flat surface?**

$$\frac{1}{f}=\frac{(n_g-n_m)}{n_m}\left(\frac{1}{R_1}-\cancelto{0}{\frac{1}{R_2}}\right)\qquad \frac{1}{f}=\frac{(n_g-n_m)}{n_mR_1}$$

R_1 = ?



$R_2=\infty$

$$R_1=f\,\frac{(n_g-n_m)}{n_m}$$

$$R_1=-36\,\text{cm}(1.51-1.33)/1.33$$

$$\boxed{R_1=-4.87\,\text{cm}}$$

This makes sense since a negative radius of curvature indicates that the center is to the *left* of the surface!

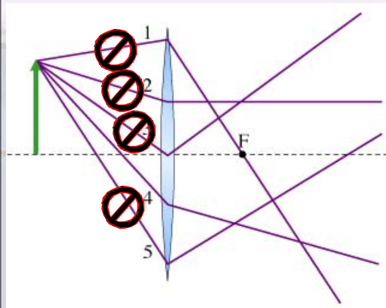
ConceptTest

If instead of being fully immersed in water, air was present on the plano side while water was present on the concave side, would the focal length:

1) **Increase**
2) **Decrease**
3) **Stay the same**

Reading Question

- Which ray is correct as drawn?



There are problems with:

#1 only parallel rays go through focus

#2 Ray would have to hit focus on object side

#3 Physically impossible!!!

5 Ray passing through focus on object side should exit parallel.

Answer: 4

Example: The Magnifying Glass

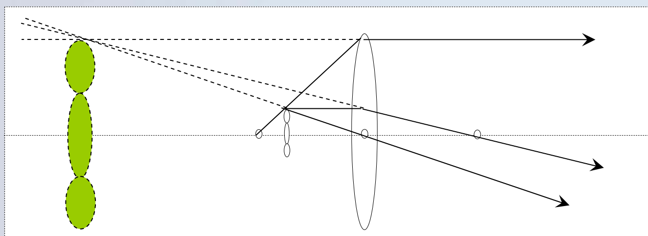
- A magnifying glass is used to examine an Ant. The image of the ant is four times bigger than the ant itself when the ant is 2.5 cm from the lens.
- From your experience, is the image real or virtual?
- Determine the location of the image.
- Draw a complete ray diagram.
- Determine the focal length of the lens.

- **Typically images are not inverted when looking through a magnifying glass, therefore assume the image is virtual!**

$$M = \frac{h_i}{h_o} = -\frac{s'}{s} = 4$$

$$s' = -4s = -4(2.5\,\text{cm}) = -10\,\text{cm}$$

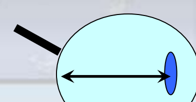
$$\begin{aligned} \frac{1}{f} &= \frac{1}{s} + \frac{1}{s'} \\ &= \frac{1}{2.5\,\text{cm}} + \frac{1}{-10\,\text{cm}} \\ &= \frac{3}{10\,\text{cm}} \\ f &= 3.33\,\text{cm} \end{aligned}$$



Example

- **The lens at the front of your eye must produce a sharp image on your retina at the back of your eyeball. If your vision is good, it can do this whether the object is 1 ft or 100 yards away. Estimate the range of focal lengths that a "good" eye can adopt.**

Approximately how big is your eyeball?
About 1 inch (say 25 mm)



What is the image distance ?
About 20 mm (fixed!)

What focal length is required for s=100 yds
About 20 mm ! (100 yds ≈ ∞ !)

$$\frac{1}{f_1} = \frac{1}{\infty} + \frac{1}{0.02\,\text{m}} = 50D$$

What focal length is required for s= 1 ft ?

$$\frac{1}{f_2} = \frac{1}{1\text{ft}}\left(\frac{1\text{ft}}{12\text{ in}}\right)\left(\frac{1\text{ in}}{0.0254\text{ m}}\right) + \frac{1}{0.020\text{ m}} = 53.3D$$

$$f_2 = 0.0188\,\text{m}$$

Example: Combinations of Mirrors and Lenses

An object lies 12.5 cm from a mirror (R =20 cm). Equidistant and on the other side is diverging lens (f = -16.7 cm). Locate the final image and determine the magnification of the entire system.